Achromatic super-oscillatory lenses

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Super-oscillation is a physical phenomenon that band-limited functions can oscillate much faster than its highest Fourier component over arbitrarily large intervals. It breaks the common belief that optical resolution in far-field is diffraction limited and the smallest focal spot size cannot be smaller than half effective wavelength. A super-oscillatory field with sub-diffraction features can be generated by delicate interference of propagating waves without any evanescent wave contributions, thus inspiring far-field super-resolution imaging applications [1]. Proliferation of nanofabrication technologies now allows us to embrace of new approaches to focusing. Using the principle of optical super-oscillations, here we report planar achromatic lenses capable of sub-diffraction focusing – beating the diffraction limit of conventional refractive lenses – and in the meantime focusing light of different wavelengths into the same hotspot. Such low cost, compact lenses could be useful in mobile devices, data storage, surveillance, robotics, space applications, imaging, manufacturing with light, and spatially resolved nonlinear microscopies.

Although the outcome of interference is wavelength-dependent, a super-oscillatory lens (SOL) can be designed to focus different wavelengths into the same spot (see Fig. 1a top). This is possible because SOL can create foci of extremely long depth [2], extending tens of wavelengths away from the mask, so foci of different wavelengths can partially overlap creating a zone of distances from the SOL where a range of wavelengths can be focused simultaneously. An alternative approach is to use super-oscillatory mask generating a number of discrete foci at different distances from it. For different wavelengths some of these foci can overlap and thus the SOL will focus two or more wavelengths simultaneously in one spot (Fig. 1a bottom). In this talk, we will describe a range of SOLs, demonstrating the wide variety of lenses that can be designed and the flexibility for particular applications. We have made both amplitude- and phase-type achromatic SOLs for infrared radiation integrated either on optical fibres (Fig. 1b) or silicon wafers (Fig. 1c), and an apochromatic red/green/blue SOL for the visible part of the spectrum (Fig. 1d).

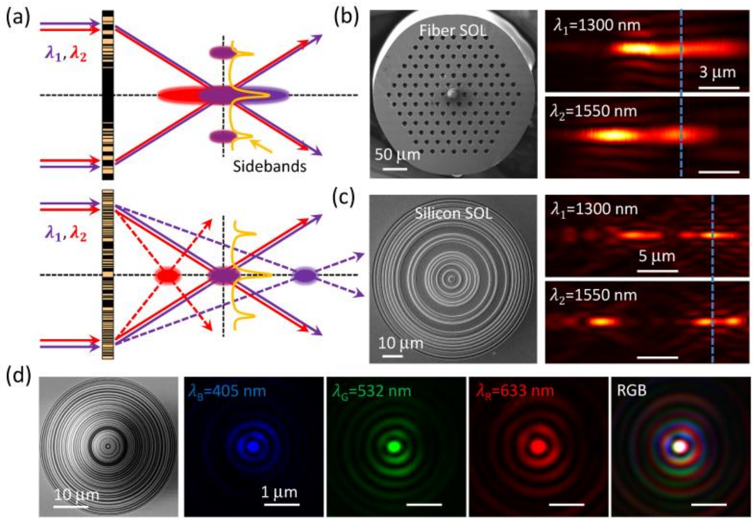

Fig. 1 (a) Two mechanisms for designing achromatic super-oscillatory lenses (SOLs): one to develop long depth-of-focus hotspot that achieving achromatic behaviours within certain overlapping region, the other to generate multiple hotspots and overlap specific hotspots with proper mask design. (b) Amplitude-type fiberized SOL and its achromatic focusing performance for two IR wavelengths of λ_1=1300 nm and λ_2=1550 nm. (c) Phase-type SOL in silicon and focusing characteristics for λ_1 and λ_2. (d) Apochromatic SOL for red (λ_R=633 nm), green (λ_G=532 nm) and blue (λ_B=405 nm) wavelengths and white super-oscillatory hotspots when turning on all the RGB channels.

References

[1] E. T. F. Rogers, J. Lindberg, T. Roy, S. Savo, J. E. Chad, M. R. Dennis, N. I. Zheludev, "A super-oscillatory lens optical microscope for subwavelength imaging," Nature Mater. **11**, 432-435 (2013).

[2] G. H. Yuan, E. T. F. Rogers, T. Roy, G. Adamo, Z. X. Shen, N. I. Zheludev, "Planar super-oscillatory lens for sub-diffraction circular polarization optical needles at violet wavelengths," Sci. Rep. **4**, 6333 (2014).